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SCIENTIFIC METHOD IN SCHOOLS

A SUGGESTION

BY

W. H. S. JONES, M.A.

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Cambridge University Press

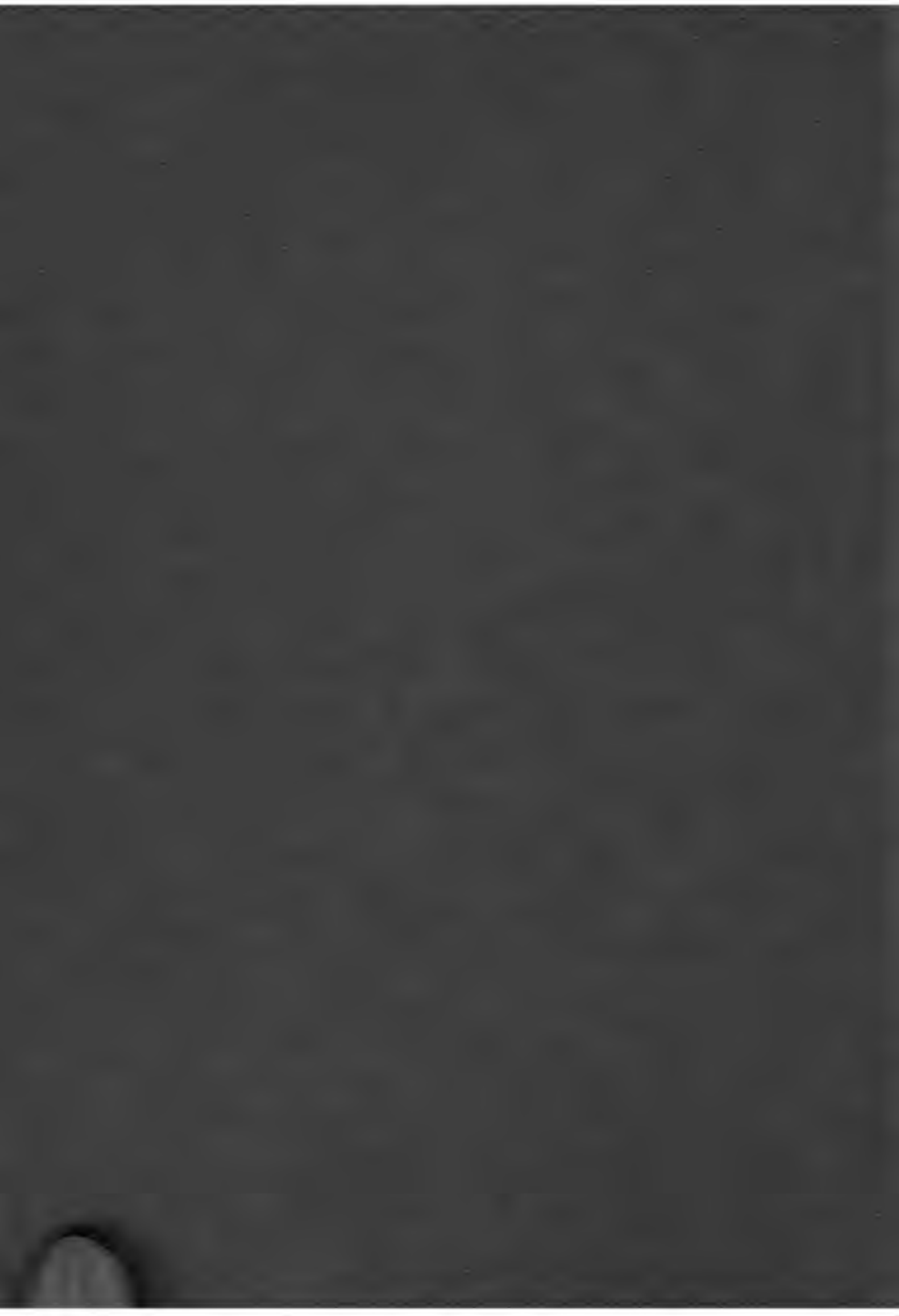
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PREFACE

IN this little essay I plead for a more rigid application of certain principles which all teachers follow more or less consciously. For twenty years I have taught pupils of all ages from ten to twenty-three in a great variety of subjects. What has impressed me most is their helplessness when face to face with a problem. They rarely know how to attack it. They are not trained, and scientific method cannot be "picked up." It is often forgotten that before accurate reasoning becomes spontaneous and automatic it must be regularly practised with conscious reference to the essential stages. Whatever the curriculum be ultimately, if each subject be made to contribute its quota to scientific training, a habit will be formed which will guide the pupil, not only in his school career, but throughout his life.

See note on p. 12

I have to thank my colleagues, especially Mr H. L. Watkinson and Mr I. H. Hersch, for much kind help, and my pupils for voluntarily working out several long exercises.

W. H. S. J.

June, 1916.

**Omnes artes, quae ad humanitatem pertinent,
habent quoddam commune vinculum et quasi
cognitione quadam inter se continentur.**

CICERO.

CHAPTER I

"They have no pretences to much clearness or precision in their ideas, or in their manner of expressing them. Their intellectual wardrobe (to confess fairly) has few whole pieces in it. They are content with fragments and scattered pieces of Truth. She presents no full front to them—a feature or side-face at the most. Hints and glimpses, germs and crude essays at a system, is the utmost they pretend to....They seldom wait to mature a proposition, but e'en bring it to market in the green ear. They delight to impart their defective discoveries as they arise, without waiting for their full development. They are no systematisers."

ELIA.

However playful Lamb's satire may be, he has certainly noted a serious failing in the ordinary Englishman, who of all things dislikes most to be forced to face facts, to search for truth, to think carefully and accurately. We prefer to have our thinking done for us and to "muddle through." The war has taught us that something is wrong with our educational system, and the cry goes up for more natural science. In a sense the demand is reasonable; we do need to become more scientific. But it is most unreasonable to suppose that a few more hours a week spent in the laboratory can work a miracle. More time must doubtless be given to chemistry, physics and biology, but a mere change in the curriculum cannot, by itself, teach us to think scientifically. The scientific mind is a product which is to a great extent independent of the curriculum, depending not so much upon the particular subjects taught as upon the spirit in which the work is

conducted. The subjects of the curriculum are chosen for utilitarian reasons—I use the phrase in its widest sense—but all subjects, in different ways and to different degrees, can be made to give a training in scientific method.

Moreover, it is probable, if not certain, that a man will be a better chemist or electrician, particularly if he be engaged in research, if his scientific training has not been confined to his special subject but rests on a firm and broad foundation. I would therefore put forward the following thesis. Whatever subjects are included in the curriculum, each one should contribute its quota to a comprehensive scheme of scientific method. This general thesis I will now explain more fully.

In the greater part of his school work a boy is being supplied with facts from which he is taught to make more or less rational guesses. This training is useful in everyday life, but is worse than useless when problems are presented the solution of which demands strict and accurate reasoning. Geometry, indeed, is a splendid example of severe deduction, but scientific induction is rarely if ever thoroughly taught. Surely a boy's mind would be a better instrument, surely his guesses would become more accurate, if every subject were made to provide a series of illustrations of rigid deduction and induction, but especially of the latter. Not every lesson, of course, can be used for this purpose, but the practice must be regular, occurring say once a week or once a fortnight in each subject. The pupil should constantly be conscious of the necessity of working according to fixed laws. The essential thing, then, is to insist upon the presence of the formal steps, whether the exercise is done by the master, as an illustration, or by master and boys in collaboration, or by the boys themselves without any help. Moreover,

it must be carefully noticed at every stage whether the reasoning is strictly or only approximately accurate, so that no possibility of error may be unperceived. Each exercise may be compared to a hunt for truth. The ways by which the quarry may escape are carefully blocked. Some ways however are too wide to be blocked, and these are noted, so that if a mistake occurs we know where to look to remedy our error. Before going on to discuss at what age such training can profitably begin, what quota each subject can best contribute, in what order the principles of scientific method are best presented, and what are the mutual relations of theory and practice, it will be well to give an actual specimen of a lesson in geography, worked out with a class of boys whose average age is about sixteen.

Problem. What are the factors which determine the position of large cities?

Step I. Collection of evidence. A perfectly reliable answer would require the minute examination of the site of every large town, both ancient and modern. As most of this evidence is out of our reach unless an impossible amount of time is spent in collecting it, we admit at once that our conclusions will be only tentative. In order to secure material with which to frame a working hypothesis, we confine our attention to twenty-five representative cities.

Step II. Classification. We examine, by means of maps and descriptions, the sites of these cities and find that they are all situated:

- either (a) in or near districts of natural wealth;
- or (b) on a trade route, whether (1) inland, or
- (2) river, or (3) ocean.

We note however that there may be essential charac-

teristics which have escaped our notice. Here lies another possibility of error.

Step III. Inference. A provisional hypothesis is framed in accordance with Step II.

Step IV. Testing of hypothesis. Five other towns are discussed, and they confirm the hypothesis. History too confirms the hypothesis, for we know in some cases why towns were founded where they are. Modern Athens is mentioned as an exception to our hypothesis. An interesting discussion follows, in which it is shown that grand scenery, healthy climate, or even sentimental reasons, may influence the growth of towns. The hypothesis in Step III is accordingly modified. Finally a warning is given that the hypothesis is still tentative, and that increased experience may require further, and perhaps considerable, modification of it¹.

✓ Very young boys are impatient and always jump to conclusions. Their minds are well adapted to the assimilation of fresh material, but incapable of close reasoning. This psychological fact must be remembered by those who would frame any scheme of study. But at about the age of twelve a boy is prepared to follow an argument, and it is then that a beginning should be made in scientific method. For four years periodical lessons of the type mentioned above should be given, the problems being taken from the work actually done in class. They will necessarily be of various types, some illustrating induction, some deduction, some probability of evidence, but in no case should any departure from strict reasoning be allowed to pass unnoted. When he reaches the age of sixteen, after this long course of combined theory and practice,

¹ At a hint from me, a pupil worked out this problem at some length. His solution is given on pp. 22-28.

a boy is ready for a short course—one lesson a week for two terms would be ample—in elementary philosophy, in which what he has learned incidentally is summed up and systematised. Jevons' primer *Logic*, with a few additions, might serve as a text-book¹. Finally in the Sixth Form, during his last term, a boy might study the history of scientific method in F. W. Westaway's *Scientific Method, its Philosophy and Practice*.

For this scheme, if carried out with faith in its usefulness, I claim several advantages.

(1) It promotes accurate thinking without adding a fresh subject to the curriculum or making any serious demands upon the time-table.

(2) It provides a basis for the teaching of the natural sciences which is both broad and firm.

(3) Above all, it gives a unity to the curriculum, thus benefiting both teachers and pupils. Teachers begin to realise that, no matter what their subject may be, they have one great purpose; pupils little by little come to see that Truth is one, and that there is one way only of reaching it.

There is in scientific method, seriously applied to the ordinary problems of life, a solvent for many of our quarrels and disputes. Nobody trained to seek truth by means of the only canons that can afford reliable help will quarrel with his neighbour over a point when reason is a sure guide. Only when scientific method has done

¹ If circumstances permit, I hope myself to write a primer for this stage. It should include (a) a discussion of thought as expressing judgments about sense-impressions, (b) a brief account of the functions of logic and of scientific method, (c) an explanation of the value and imperfection of language as a means of expressing thought, (d) the essential principles of scientific method.

its work, only when the problem is presented in its elemental form, will such a man take sides, and join one party or other according to the promptings of his emotions, those primary instincts of right and wrong, good and bad, which defy analysis, so that reason appeals to them in vain.

The material for a first beginning is to be found in the English lessons. Here can be taught the necessity for precision in the use of words, the value of definitions and the characteristics of a good definition. However difficult the process, a boy should gradually be brought to see that the meaning of a word to an individual is merely a summary of that individual's experience in connexion with that word. He will then realise that, to avoid confusion and error, he must eliminate from the meaning he attaches to a word all that is peculiar to himself, and form a correct notion of that common element shared by all reasonable minds. Grammatical rules, if carefully taught, will illustrate collection of evidence, classification and inference. The pupil will learn that a rule is but a summary of experience. What is true of English is true, *mutatis mutandis*, of foreign languages.

Nature study is an invaluable instrument. The importance of collection of facts and of classification can be driven home again and again, and if the pupil has a garden to work in, he can learn the value of experiments, and the supreme importance of a crucial experiment.

Mathematics, especially geometry, will afford instance after instance of perfect deduction, and a very little trouble on the part of the teacher will make even the dullest familiar with the steps and laws of a valid syllogism.

Geography is as useful as nature study for illustrating the principles of induction.

History breaks new ground, for it introduces the pupil to the difficulties of testing evidence and estimating probabilities.

The natural sciences, like nature study, differ from other subjects in that they deal with forces over which the pupil has some control, while his aim is to acquire yet more. So it is here that experiment finds fullest scope, and the pupil is most thoroughly freed from the necessity of relying upon authority. It is of great importance that each pupil should realise at the earliest possible period that a natural law is merely a summary of sequences of phenomena, and that one experiment is insufficient for a generalisation unless we assume the uniformity of nature.

A critic may urge that however specious this scheme may appear on paper, it is worthless without the supreme test of experience. It is true that I have not given it the full and searching trial I should like to give; only a headmaster has the opportunity to do so. But wherever I or my colleagues have applied a partial test, it rings true. I have myself used it most with advanced pupils in a Sixth Form and at the University when dealing with problems of ancient history, philosophy and syntax.

I have found that the best results were obtained by attacking (say) a history problem in the following way.

(1) The extant evidence (or the most pertinent parts of it) is placed before the pupil with a warning to remember its fragmentary nature. The pupil is then asked to state clearly in his own words what exactly are the *data* afforded by these ancient authorities.

(2) The evidence is examined to discover whether it admits of classification.

(3) The credibility of the *data* is tested by examining whether the information is confirmed or contradicted by:

(a) extrinsic evidence;

or (b) intrinsic evidence.

It is at this stage that ample opportunities occur of discussing how to estimate the probability of any statement.

(4) A hypothesis is formed separating as far as possible the truth of the *data* from the untruth.

(5) The hypothesis is tested by seeing how far what we have decided to be true in (4) fits in with the known history of the period referred to.

Not all historical problems lend themselves to this elaborate treatment, but most if not all syntactical difficulties can be handled in the following way:

(1) An example of a grammatical irregularity is examined, and the part needing comment is noted.

(2) The syntactical rule is quoted, fully and accurately, with which the given example disagrees.

(3) Can the exception be explained? In particular has analogy been working?

(4) Can similar exceptions be quoted to support the hypothesis of (3)?

I have been agreeably surprised by the improvement that a training on these lines produces in undergraduates within a few weeks. But obviously the results would be far better if the training were begun in early boyhood and graduated according to the mental development of the pupil until he came to the University. The full results of any such scheme as mine are cumulative.

It is perhaps unnecessary nowadays to emphasise the importance of manual training, and I would merely urge that care in practical experiments will react on the mental side of scientific training.

Finally teachers and the general public cannot be reminded too often of the truism that scientific method can only give us the means to attain our ends or aims. It cannot give us ideals; and unless the rising generation is going to consist of clever, scientific rogues, teachers must see to it that the demand for efficiency does not harm other sides of education equally if not more important.

CHAPTER II

I now give a few examples of the kind of exercise I advocate. They are by no means intended to be models. Lessons actually given in class and schoolboy answers printed without corrections contain many mistakes and imperfections which it were well to avoid. But they serve a very useful purpose; they not only mark possible dangers but also show what has actually been achieved. The exercises here given as done by boys without help would have been better if the writers had gone through the preliminary course. But, as I have already stated, I have not been able to give the scheme a full trial. With older pupils continuous work has been done, with younger pupils only occasional lessons have been given as opportunity occurred. It is for this reason that I cannot include any exercises done by young boys without help. Only after a time, when a whole series of problems has been solved by master and boys together, can young pupils be trusted to work unaided. It should be noticed, however, that in all the lessons the boys' minds are fully active. The master does not instruct; he merely suggests and guides.

Only one of the pupils' problems (number VIII) was in any sense due to me. In all other cases I simply asked for a problem to be worked out, leaving the choice of subject and the treatment to the pupils themselves. These pupils are all on the classical side.

(A) Worked out by master and boys together.

(B) Exercises done by boys without help.

EXAMPLE I

(A) AVERAGE AGE OF CLASS THIRTEEN.

Problem. The meaning of the word "stupid."

Collection of evidence. Various synonyms are proposed by the boys: "foolish," "idiotic," "silly," "dull." One boy suggests (and is commended for the suggestion) that there is no exact equivalent.

Classification. A discussion follows, in which the above synonyms (all of which imply *irrational conduct*) are discriminated. The teacher gives examples, and the boys come to see that the *idiot* is one whose conduct reminds you of a madman; *silliness* is excess of simplicity (simpleton); the *foolish* man is one who sees what is to his interest, can do it, but does not. E.g. to remain in wet clothes when you can change them, and know the danger of not changing them, is foolish. The *dull* man does not perceive what the ordinary man can perceive.

Hypothesis. Stupidity is defined as excess of dulness.

Test of hypothesis. The teacher points out that this definition is a summary of the experience of the class. It is necessary to find out whether the usage of the general public bears out the provisional hypothesis. So the dictionary is consulted, which confirms the definition. Instances are quoted from literature, the derivation of the word is given, and cognate words, such as "stupefy," are mentioned.

A similar exercise has been done with the Latin word *pius*. When the boys meet it in the *Aeneid* for the first time they are warned that it will often recur, and that

they must collect instances. After a sufficient number of examples have occurred, a hypothesis is framed as to its meaning, which hypothesis is tested later on.

EXAMPLE II

(A) BEGINNERS IN LATIN, AVERAGE AGE TWELVE.

Problem. To discover the rules for the agreement of the relative.

Evidence. This is presented in the form of a series of exercises, the first containing sentences in which the relative is constantly used, the second sentences in which *et is, et eos* etc., have to be changed into *qui, quos* etc., the third sentences in which the relative is omitted and has to be supplied.

Examination of evidence. The boys are asked to observe the number, gender and case of each relative, and to try to discover what determines these three things. The exercises are now worked through, only a few mistakes being made.

Inference. The boys observe, without being told, that the number and gender of the relative are fixed by the antecedent, and that its case depends upon its own clause. The teacher has to explain that the relative, like any other pronoun, can be subject, direct object, indirect object etc., to its clause.

Test. Subsequent instances of the relative are examined to see if they conform to the rule.

EXAMPLE III**(A) AVERAGE AGE OF CLASS TWELVE.**

The problem is to discover by experiment why the leaves of the common Furze bush are prickly, hard and different from the ordinary type of leaf.

I. The first step is to discover the kind of conditions in which the Furze lives. A visit to any heath or moorland will discover to the pupils that the Furze lives in open, hilly and stony wastes, where there is no depth of soil for the roots.

The following questions arise—Of what use is the soil to the plant? The answer will give a clue to the problem. The soil gives nourishment to the plant, but water is necessary in order that the salts of the soil may pass into the plant roots. But how can the presence or absence of water affect the shape of the leaf? The leaf is the organ of interchange between the plant cells and the atmosphere. Through the stomata of the leaf water-vapour passes to and fro. In a dry place, however, the plant must part with its water with great care, for a future supply may be very uncertain: obviously then the plant must make the leaf surface of such a shape and kind that the least possible quantity of water is lost. At once a reason for the shape of the Furze leaf is suggested.

II. We have now a hypothesis which must be tested. We must grow a Furze seedling in conditions totally different from the usual. We must grow the seed in a habitat where water is very plentiful and observe the result. It will be found that the leaves of this new plant

are soft and succulent, and in general characteristics approximate to the usual type of leaf.

The result of this experiment gives *the* reason for the peculiar form and shape of the Furze leaf.

EXAMPLE IV

(A) AVERAGE AGE OF CLASS TWELVE.

Notes on Classification—the Natural Order Cruciferae.

The lesson is obviously one in which certain specific knowledge gained in previous lessons is to be applied to formulate a general principle or scheme by which flowers can be classified and divided into family groups. The treatment of the subject can be divided into the following divisions.

I. Recapitulation of the knowledge gained—in this case a brief survey of the parts and functions of the parts of any flower.

II. A minute study of the flower which is to stand as a type of the particular kind of flowers to be studied. For example in the specimen (the Wallflower) it must be noted that there are four petals, four sepals, six stamens and a two-celled ovary. This step must be followed by an examination of other four-petalled flowers such as the Shepherd's purse, the Cuckoo flower (*Cardamine pratensis*), the Candytuft, and the observations must be classified as follows—

| Flower | Calyx | Corolla | Andræcium | Gynœcium |
|------------|----------|----------|-----------|--|
| Wallflower | 4 sepals | 4 petals | 6 stamens | 2-celled ovary 2-lobed stigma Fruit: a pod |

From such a table the generalisation—some flowers have four petals, and four sepals, six stamens arranged in groups of four long and two short and a two-celled ovary—is easily obtained.

III. The next step is the testing of the generalisation by an examination of as many Cruciferae as is possible.

IV. Finally the whole problem must be reviewed and revised, and the method of procedure criticised and stated—e.g.

- (i) need for a classification of flowers;
- (ii) to find a type of flower suitable for classification purposes;
- (iii) to compare this type with similar flowers rejecting the dissimilar and accepting the similar;
- (iv) to obtain a general test to be applied to flowers in order to class them as Cruciferae.

EXAMPLE V

(A) UNDERGRADUATES.

τὸ μέλλον καρδία πῆδημ' ἔχει. Euripides, *Bacchae*, 1289.

Problem. What is the construction of τὸ μέλλον?

General rules. It cannot be nominative. Therefore it must be accusative. There is no preposition to govern it, therefore if not an accusative of general reference it should be governed by a transitive verb.

Hypothesis. καρδία πῆδημ' ἔχει, though not a transitive verb, is equivalent to one, viz. φοβούμαι. Perhaps, therefore, it takes the same construction (analogy).

Test. Exact parallels can be quoted, e.g.,

εἰ δέ μ' ᾧδ' ἀεὶ λόγους ἐξήρχες.

Sophocles, *Electra*, 556.

λόγους ἐξήρχες = προσήυδας.

EXAMPLE VI

(A) CLASS OF UNDERGRADUATES.

Problem. The nature of the agreement after the battle of the Caudine Forks.

Evidence. The teacher refers to (a) Livy ix 5:

Itaque non, ut vulgo credunt Claudiusque etiam scribit, foedere pax Caudina, sed per sponsionem facta est. quid enim aut sponsoribus in foedere opus esset aut obsidibus, ubi precatione res transigitur, per quem populum fiat, quo minus legibus dictis stetur, ut eum ita Iuppiter feriat, quem ad modum a fetialibus porcus feriatur?

and (b) Cicero *de Inv.* II 30. 91:

In eo foedere, quod factum est quondam cum Samnitibus, quidam adulescens nobilis porcum sustinuit iussu imperatoris. Foedere autem ab senatu improbato et imperatore Samnitibus dedito, quidam in senatu eum quoque dicit, qui porcum tenuerit, dedi oportere.

The teacher explains *foedus* and *sponsio*, pointing out that the former had a religious, the latter a moral sanction.

Data. The class is asked to re-state the evidence.

- (1) Livy says that the Caudine Peace was a *sponsio*.
- (2) Cicero assumes that the Caudine Peace was a *foedus*.
- (3) The bargain, whatever its nature, was confessedly repudiated as being disadvantageous.
- (4) Both traditions imply that the public conscience was uneasy because of the repudiation.

Credibility. Of the two traditions which is the more credible? If the bargain was a *sponsio* there is no reason

why some Romans should declare it was a sacred *foedus*; but if it was a *foedus* there is every reason why Livy, who wrote with a purpose, should desire to make out that it was a mere *sponsio*.

Inference. The bargain was a *foedus*.

Test. This conclusion fits in well with Livy's tradition of the Caudine disaster. The whole account is open to suspicion on intrinsic grounds. It is full of improbabilities, and there is a desire both to minimise the disaster and to excuse the Romans' repudiation of the bargain.

EXAMPLE VII

(B) AGE OF PUPIL SEVENTEEN.

Problem. Is there any common origin of the folk stories of England, Germany, and the Celtic countries?

In order to decide this question, it would be necessary to collect all the known stories, both those still handed down by tradition, and those that were traditional in former times. Even if this were possible, my evidence would not be complete; for a large number of stories have never been handed down to the present day, and have never been written down. All that I can do is to examine the collections which have been made of the various stories belonging to the various countries. There is every evidence that these collections have been made directly from the people: but it may be argued that there is no evidence that the people who tell the stories did not invent them themselves. This last alternative, however, can be practically eliminated, since we know that the imaginative element (of people) in this form has been

fast deteriorating with the introduction of modern civilisation. I will therefore proceed to examine what evidence can be obtained from these collections.

Evidence. (1) The German *Däumling* has many details precisely the same as the English "Tom Thumb" or "Tom a lyn" (cf. the Scandinavian Thaumlin), e.g. the size of the hero and his adventures etc.

(2) The German "King of the Golden Mountain" contains giants similar both to those in English "Jack the Giant Killer" and the giants of Celtic stories (cf. also Scandinavian Thor).

E.g. giants are deprived of shoes and sword.

They mistake big articles for something minute.

(3) The German "Giant with the Golden Hair" is in many details like the English "Jack and the Bean Stalk."

E.g. giants in both cases smell out their victim.

(4) The three sons are found frequently in stories of all three countries; the youngest son is the despised one who is in the end successful.

There are very numerous examples of this.

| | |
|---|--|
| E.g. German "Three Children of Fortune" | } In each of these a despised animal is given. |
| English "Puss in Boots" | |
| Celtic "Black Horse" | |

(5) More examples of the despised younger son being a simpleton are particularly prominent in German "Jack the Dullard," and Celtic "The Lad with the Goatskin."

(6) Stories about animals are frequent in all three countries.

E.g. German "Travelling Musicians" is precisely the same story in outline as the Celtic story "Jack and his Comrades," except that in the latter a man is introduced

as the original hero. This idea of man being helped by animals he has aided can also be found in the German "The Grateful Beasts."

(7) The German "Lady and the Lion" has a similar story to the English "Beauty and the Beast."

(8) The German "King Grisly Beard" contains a story found in most nations, similar to that told in "The Taming of the Shrew."

(9) The German "The Frog Prince" is very like a story known in Scotland as "The Frog Lover."

(10) The English "Cinderella" is found in almost exactly the same form in the German, while the Celtic "Fair Brown and Trembling" has many points, in the main thread of the story, identical with them.

(11) The German "Big Claus and Little Claus" contains the main ideas in the Celtic "Hudden, Dudden and Donald o' Neary," with only the difference of the number of characters.

(12) The German "Snowdrop" is very nearly the same as the Celtic "Gold Tree and Silver Tree."

(13) The German "Rose Bud" is the same story as the English "Sleeping Beauty" and the Celtic "Deirde."

(14) We find many details in these various stories resembling one another.

E.g. (a) The Testing of Strength, by making three swords.

(The first two are broken by the hero as too weak.)

This is found in German "Hop o' my Thumb," Celtic "Sea Maiden," English "Arthur and Merlin" (and in the Scandinavian the sword made for Thor).

(b) Ideas about eating children found in German "The Juniper Tree" and Celtic "Small-head."

(15) The English nursery tale "How the Pig got over the Stile" is comparable in its main idea to the Celtic "Munachar and Manachar."

Classification of evidence. I know that these examples are incomplete, and that no working theory can be formed merely from these instances of similarity. But it is an undeniable fact that the more we examine the folk stories of these countries, the more we find similarities, while in some cases very nearly the same story can be traced.

Thus we have given five stories of which the main idea is found in all three countries, seven stories of which the main idea is found in two countries, and four stories in which there are details common to two or all three of the countries.

Hypothesis A. From these pieces of evidence it is natural to form the hypothesis that primitive countries, in their period of handing down imaginative stories, tend to have the same ideas, varied according to their particular form of religion or of native genius.

Testing A. Do these stories have any resemblance to those of other and more remote countries?

(a) We find in Celtic stories very similar ideas about giants to those told about the Cyclops—e.g. the giants have one eye, and the method of self-defence by the hero is to blind that eye. In both cases he then escapes by means of the cattle belonging to the giant.

(b) We find that the old stories from which Ovid took his *Metamorphoses* resemble very much some of the Teutonic and Celtic stories, e.g. the changing into animals occurring in "The Frog Prince," "Frog Cherry" etc.

(c) A large number of the stories about animals have

a very moral character, and resemble distinctly the stories of the east, found both in Indian tales, and in Aesop's fables.

But none of these instances include similarity so complete that the main thread of the story is the same. In the case of "Cinderella" however, we have seen that the same story is actually told. Hence our hypothesis does not seem to go far enough. It seems to account for the general similarity between folk stories, but not for the fact that identical stories are found in the three countries.

Hypothesis B. Hence we naturally suppose that, besides the usual similarity of folk stories of all nations, there is either some common origin in the German, English and Celtic myths, or these peoples have intermingled to such an extent that many of their stories have become identical.

Testing B. (a) From the linguistic and racial point of view we know that England and Germany both belong to the Teutonic race, and that a common origin is probable.

(b) From the linguistic point of view the Celtic seems entirely removed from the Teutonic, and it is practically impossible for me to judge whether the Celtic races had some common origin with the Teutonic, or whether, at some date, they intermingled.

Hence my first hypothesis was insufficient, while my second hypothesis cannot, by me at any rate, be proved.

B

EXAMPLE VIII

(A) AGE OF PUPIL SEVENTEEN.

Problem. Why are large towns situated where they are?

STAGE 1. COLLECTION.

N.B. Here is need of an obvious caution. It is impossible, for me at least, to collect the evidence of all the towns that ever were. Many have long since perished, and of those thousands now existent we can hardly examine more than a few. Let us take then, roughly speaking, the world's chief cities as fair examples of the whole.

London. On the mouth of the Thames. Harbour.

Ancient military position.

Edinburgh. On a mount commanding the whole neighbourhood.

Dublin. On a natural harbour. River.

Paris. On a navigable river, at junction with two tributaries.

Brussels. On small river. Central position in kingdom.

Amsterdam. River mouth.

Berne. Fertile region. Valley (trade route).

Berlin. Fertile plain.

Stuttgart. Trade valley.

Munich. Trade valley.

Breslau. Fertile region. On river.

Warsaw. River. Fertile region.

Petrograd. Harbour and river.

- Moscow. Fertile region. Between two large rivers.
Vienna. Fertile river valley used as trade route.
Pest. Where trade river flows into fertile plain.
Belgrade. Confluence of two rivers. Important military position.
Bukharest. Central position in fertile plain.
Sofia. Junction of two valleys. Mountain fastness.
Constantinople. Commanding Bosphorus. Harbour.
Athens. Ancient stronghold. Harbour.
Scutari. Very fertile. On lake (fishing?).
Cettinje. Mountain fastness.
Naples. Fertile bay. Good harbour. Health resort.
Rome. On river. Stronghold.
Turin. River. Where trade route enters fertile plain.
Milan. Central position in fertile plain.
Venice. Head of Adriatic, and at mouth of trade river. Lagoon harbour.
Lisbon. River and harbour.
Madrid. On commanding position near long and wide river. Fertile.
Copenhagen. On island commanding The Sound. Thus military and trading centre.
Christiania. River and harbour. Fertile valley.
Stockholm. Harbour. Fertile region.
Cairo. Mouth of river. Near fertile delta.
Aden. Trade route. Military position commanding both straits and interior.
Calcutta. River. Fertile delta with many harbours.
Madras. River. Military position.
Bombay. Harbour.
Colombo. Outlet from interior. Harbour.
Timbuktu. Where desert trade route joins river (most northerly point). Oasis.

- | | |
|---|--|
| Sydney. Harbour | } Apparently just where the exploring navigator happened to strike the coast, which is full of harbours quite as good and even better. |
| Brisbane. Harbour | |
| Adelaide. Harbour | |
| Wellington. Harbour | |
| Dunedin. Harbour | |
| Perth (W.A.). Harbour in fertile region (two rivers). | |
| Hobart. Sheltered harbour (island in front of coast). | |
| Cape Town. Harbour and military position. | |
| Bloemfontein. River. Fertile plain. | |
| Pretoria. Native trade centre. River. | |
| Durban. Harbour. | |
| Pekin. Fertile plain. Between two great rivers. | |
| Seoul. Near harbour. Only large river from interior. | |
| Tokio. Harbour. | |
| Kioto. On lake surrounded by hills. (? Fertility.) | |
| Sparta. Military position. | |
| Thebes. Fertile plain. River. Military position. | |
| Amphipolis. Harbour. Outlet for gold trade. | |
| Tegea. Fertile plain. | |
| Kimberley. Mines. | |
| Brighton. Health resort. | |
| Corinth. | } Isthmus on trade route. |
| Sybaris. | |
| Carthage. Harbour. Military position. | |
| Nineveh. | } Trade route (river). Fertile compared to desert. |
| Babylon. | |
| Mycenae. Harbour. Military position. Fertile region. | |

STAGE 2. ARRANGING.

| | |
|---|----------|
| I. Trade Route:—Paris, Stuttgart, Munich, Pretoria, Corinth, Sybaris. | 6 |
| II. Harbours:—Bombay, Sydney, Brisbane, Adelaide, Melbourne, Wellington, Hobart, Dunedin, Durban, Tokio. | 10 |
| III. Fertility ¹ :—Berlin, Scutari, Tegea, Kimberley, Kioto (?). | 5 |
| IV. Military Position:—Edinburgh, Cettinje. | 2 |
| V. Central Position:—Brussels. | 1 |
| VI. Health Resort:—Brighton. | 1 |
| | <hr/> 25 |
| I and II:—London, Dublin, Amsterdam, Petrograd, Constantinople, Venice, Lisbon, Colombo, Seoul, Amphipolis. | 10 |
| I and III:—Berne, Breslau, Warsaw, Moscow, Vienna, Pest, Turin, Madrid, Cairo, Timbuktu, Bloemfontein, Pekin, Nineveh, Babylon. | 14 |
| I and IV:—Sofia, Rome, Copenhagen, Aden, Madras, Sparta. | 6 |
| II and III:—Stockholm, Perth W.A. | 2 |
| II and IV:—Athens, Cape Town, Carthage. | 3 |
| III and V:—Bukharest, Milan. | 2 |
| | <hr/> 37 |
| I, II and III:—Christiania, Calcutta. | 2 |
| I, III and IV:—Thebes, Belgrade. | 2 |
| II, III and IV:—Mycenae. | 1 |
| II, III and VI:—Naples. | 1 |
| | <hr/> 6 |

¹ This is meant to include all natural resources and riches of the land, as mines, etc.

STAGE 3. INFERENCES.

1. There are six main reasons for the situation of towns: trade routes, harbours, fertility, military position, central position, health.

2. Most towns are built with a view to two of the above reasons, except Australian towns, springing up merely because they happened first to give shelter to the exploring navigator.

3. There is little or no evidence of the element of chance, except in so far as harbours were apparently chosen indiscriminately on a coast rich in them.

STAGE 4. TENTATIVE HYPOTHESIS.

All towns are situated either on trade routes, or on harbours, or in fertile regions, or in positions of military or naval importance, or in central positions convenient for exercising surveillance over a district, or in a particularly bracing spot for the purpose of recreating health; but generally towns are founded with a view to two or more of these functions.

STAGE 5. TESTING.

| | | | |
|-----------------|--------------|-----------------|---------------------|
| Manchester. | Explained by | III and V | } surveillance over |
| Leeds. | „ | III and V | |
| Sheffield. | „ | III, (? V). | } smaller towns. |
| Orléans. | „ | III, I. | |
| New York. | „ | II, I. | |
| Quebec. | „ | II, I. | |
| Port Elizabeth. | „ | II, I, (? III). | |

| | |
|-----------------|--------------------------------|
| Washington. | Explained by V, II, I, (III?). |
| New Orleans. | „ I, III. |
| Chicago. | „ I. |
| Prague. | „ I, IV, V, (III?). |
| Larissa. | „ III, V. |
| Salonika. | „ I, II. |
| Smyrna. | „ I, II, III, IV, V. |
| Kiev. | „ I, V, (III?). |
| Königsberg. | „ II, I, IV. |
| Riga. | „ I, II, III, IV, V, VI. |
| Sevastopol. | „ II, III, IV, VI. |
| Adrianople. | „ IV, I, III. |
| Klausenburg. | „ V, III. |
| Quito. | „ III (mines), IV. |
| La Paz. | „ IV, III (mines). |
| Panama. | „ I. |
| Monte Video. | „ II, IV. |
| Rio de Janeiro. | „ II, V. |
| Santa Cruz. | „ II, (III?). |
| Valparaiso. | „ V (as port to Santiago), II. |
| Irkutsk. | „ II, V, (IV?), (III?). |
| Blackpool. | „ VI. |
| Nice. | „ VI. |
| Spa. | „ VI. |

BUT

| | |
|------------------|---|
| Jerusalem. | Though partly IV, III, V, yet partly because of religious interest. |
| Bury St Edmunds. | Solely because of abbey. |
| Ely. | Though partly IV, V, III, II, yet largely because of cathedral. |
| Cambridge. | Though partly IV, I, V, yet largely from educational interest. |

STAGE 6. EMENDING.

Thus the hypothesis falls through, or at least has to be emended. Thus we finally arrive at

STAGE 7. FINAL HYPOTHESIS.

All towns are situated either on trade routes, or harbours, or in fertile regions, or positions of military or naval importance, or in central positions convenient for exercising surveillance over a district, or in a particularly bracing spot, or at a locality of peculiar religious or other such interest or importance; but generally towns are founded with a view to at least two of these functions.

EXAMPLE IX

(B) AGE OF PUPIL EIGHTEEN.

Problem. Is there any morphological or semantic principle underlying Homeric picturesque adjectives?

I. To find out this we must first collect evidence, i.e. gather together a good many examples of picturesque adjectives as used by Homer.

εὐρυκρείων Ἀγαμέμνων, wide-ruling. *Od.* 3, 248.

γλαυκῶπις Ἀθήνη, grey-eyed. *passim*.

ἐυρραφέεςσι δοροῖσιν, well-stitched. *Od.* 2, 354.

νύμφαι ἐνπλόκαμοι, with beautiful hair. 12, 132.

νεὸς κυανοπρόροιο, with dark-blue prow. 9, 539.

ῥοδοδάκτυλος Ἥως, rosy-fingered. *passim*.

ῥῖες δασύμαλλοι, with thick wool. *Od.* 9, 425.

καλλίτριχα μῆλα, with beautiful wool. 9, 336.

ἡμίονοι ταλαεργοί, patient in toil. 4, 636.

- ἐνδμήτων ἐπὶ βωμῶν, well-built. 7, 100.
 ἀργυρότοξος Ἀπόλλων, with silver bow. 7, 64.
 χρυσόθρονος Ἄρτεμις ἀγνή, with throne of gold. 5, 123.
 οἶκον ἐς ὑψόροφον, high-roofed. 5, 115.
 χθονὸς εὐρυοδείης, wide-wayed. 11, 52.
 Ἑκτορι χαλκοκορυστῇ, brass-armed. II. 5, 699.
 καλλίζωνοι γυναῖκες, with beautiful girdles. 7, 139.
 Ἀρκάδες ἐγχεσίμωροι, practised in spear-fighting. 7, 134.
 νηῶν ὠκυπόρων, fast-sailing. 10, 308.
 Ὀδυσσεὺς ποικιλομήτης, with various wiles. 11, 482.
 καλλίρροον ὕδωρ, beautifully flowing. 12, 33.

II. The above examples selected at random must now be classified in some way. The most obvious classification would seem to be the following:

(i) *Abstract epithets of character, or skill, etc.*
 ταλαεργός, ποικιλομήτης, ἐγχεσίμωρος.

(ii) *Epithets describing the person itself.* γλαυκῶπις, ἑρραφής, ἐνπλόκαμος, κυανόπτερος, ῥοδοδάκτυλος, δασύμαλλος, καλλίθριξ, ἐύδητος, ἀργυρότοξος, ὑψόροφος, εὐρύδεια.

(iii) *Epithets describing remarkable possessions of the person.* ἀργυρότοξος, χρυσόθρονος, χαλκοκορυστής, καλλίζωνος.

(iv) *Epithets describing an action.* εὐρυκρέων, καλλίρροος, ὠκύπορος.

Of course, I am aware that, having collected but few instances out of the many at hand, I may have omitted a further class than the above four. The more the examples collected and classified, the more certain the hypothesis.

III. (i) Now let us consider the above picturesque epithets. Their form first draws our attention. Each

one has one division (this is immediately obvious) dividing it into two more or less equal parts, each containing a distinct idea, and qualifying the other.

Our first hypothesis will then be: Homeric picturesque adjectives are composed of two distinct ideas, each forming one-half of the word.

(ii) As regards the meaning, the obvious characterising mark which belongs to all the above examples is that they all denote a permanent or characteristic quality of the person or thing qualified. We do not find, for instance, such an adjective as, say, "with sleepy-looking eyes," unless the person thus qualified have habitually drowsy eyes. Nor do we find such a one as "with wet cheeks," unless the person be continually or habitually weeping.

Our second hypothesis will then be: Homeric picturesque adjectives always denote some lasting or characteristic, never a momentary, quality.

IV. Having thus made our hypotheses, we will now proceed to test them, by collecting further examples of picturesque adjectives as used in Homer, and finding out whether they fit those hypotheses.

βοῶν ὀρθοκραϊράων, with straight horns. *Il.* 8, 231.

Τροίην εὐρύαγυιαν, with wide streets. 9, 28.

ἐριαύχενας ἵππους, with high-arching neck. 10, 305.

αἰετὸς ἀγκυλοχείλης, with hooked beak. *Od.* 19, 538.

οἶνος μελιηδής, honey-sweet. 21, 293.

μεγαθύμου Πειριθόιοι, magnanimous. 21, 296.

πολυμνήστη βασιλεια, much wooed. 23, 149.

αἰγανέας δολιχαύλους, (spears) with long iron sockets. 9, 156.

The two hypotheses suit equally well the above

examples picked out at random. The more examples we collect for this test purpose, the more certain will the hypotheses be.

Having been thus tested, our hypotheses become now theories, and remain so until disproved by some exception.

(N.B. *νηῶν ὠκυπόρων*: the epithet here does not mean "sailing fast" at *any particular time*, but is a stock or characteristic epithet like the others, as is proved by the passage quoted:

Νηῶν ὠκυπόρων σχεδὸν ἐλθέμεν—scil. "to go near them on land." *Il.* 10, 308.)

I feel that, in proposing the problem, I should have specified Homeric picturesque adjectives as;—

(i) those which are used by Homer, and not at all, or, at any rate, but seldom, by later writers.

(ii) those, one of whose elements is not a "lifeless" particle or preposition (such as are plentiful in post-Homeric Greek). No element in the adjective must be "lifeless," but one of "colour," so to speak.

EXAMPLE X

(B) AGE OF PUPIL FIFTEEN.

Problem. What are the facts which determine the markings and colours of freshwater fish?

Evidence. Let us examine the markings of the following fish, and try to see the use of them:—

(a) The pike. Coloured dark green with shading on the back, light green and white underneath. He swims chiefly in mid water, and eats small fish, living both on the bottom and on the surface. His markings render him almost invisible from above or below.

(b) The trout. Lives often in clear streams and his spotted skin thus enables him to be almost invisible to his great enemy, man, against the gravel bottom.

(c) The roach. Lives chiefly on the bottom, and is coloured either dark green, brown, or black according to the locality, and white underneath. His big enemy the pike nearly always attacks from above; and it is from here that he is most invisible.

(d) The perch. Lives in streams with sandy bottoms, against piles and other such things. His brown and black striped back, while he is white underneath, renders him almost invisible to the small fish that form his prey.

(e) The dace. Lives either on the bottom or the surface; is coloured black or dark green accordingly on the back, and is a bright silvery colour underneath. His enemies, the pike and the perch, both attack from below him when he is on the surface, but his colour protects him well.

(I know I am liable to err here owing to my limited knowledge of the habits of fish, and total ignorance even of the existence of some small species.)

Classification. Most freshwater fish are similar to one of the species described above. Then we may classify as follows; (i) Fish which take the colour of their surroundings to capture their prey. (ii) Those which do so to escape from their enemies. We now frame our hypothesis:—

Hypothesis. Freshwater fish have their colour influenced by their surroundings and habits with a view to (i) escape from their enemies; (ii) catching their prey.

Testing. We now try to prove this by seeing how the habits and colour of other fish fit it.

(1) Bream; is a bottom-feeding fish, subject to attacks from pike. It is therefore dark-coloured.

(2) Tench and carp are rather similar. They live on the bottom and are therefore dark-coloured, to protect them from the pike.

(3) Bleak; is a surface fish with habits and markings similar to the dace.

(4) Gudgeon; lives on gravel or muddy bottom and is more or less muddy coloured with spots, according to the locality.

Thus, none of these fish being contrary to the hypothesis, this hypothesis is so far correct.

Among the fish I have omitted to mention are:—chub, rudd, char, loach, minnow, grayling and barbel.

EXAMPLE XI

A BOY'S ACCOUNT OF EXPERIMENTS PERFORMED IN CLASS. THE DIAGRAMS ARE OMITTED, BUT WERE CORRECTLY DRAWN BY THE BOY, WHOSE AGE IS THIRTEEN.

Problem. To find the law of pulleys.

We first asked ourselves how many attempts we should have to make before getting a result that applied to all cases. We first used one pulley with a 200 gram weight suspended from the pulley, and this supported by two spring balances.

Then we made our law—that *when a weight is suspended by a pulley the tension on each string is half that of the weight*. We then asked ourselves—does this law apply in all cases? We therefore put on another pulley. But now we found that the tension of the *C* string was 100 and *A* and *B* 50 each.

So we then improved on our law and said:—*when a*

weight is suspended by two pulleys the tension of the strings above is half that of the strings below.

To prove this again we put on another pulley. This failed, for in our third result we found the readings impossible. The scales read 20 grams, each millimetre indicating 20 grams. We therefore put on 400 grams. We then took readings. For these results we had to change our law. We said—*when a weight is suspended by a number of pulleys the tension of each string is half the tension of the string below.*

We then thought of all possible cases when strings and pulleys were arranged thus. So far we had had parallel strings. So we moved the *A* string along to the right. We found a defect then in our law, for the readings did not agree with the law. *A* readings were 70.

$$2 \times 70 = 140,$$

$$2 \times 140 = 280,$$

$$2 \times 280 = 560.$$

Which is far too much. We accordingly altered our law saying—*when a weight is suspended by a number of pulleys, the tension of each string is half the tension of the string below if the strings are parallel.*

To prove this we removed *A* balance, replacing it with a pulley and 50 gram weight. This was a fixed pulley making no difference at all except that it was fixed. But this showed the one remaining defect, that the pulleys must be loose ones.

Our law now read:—

When a weight is suspended by a number of loose pulleys the tension of each string is half the tension of the string below, if the strings are parallel¹.

¹ The mistakes in this exercise are very instructive.

CONCLUSION

In the preceding pages I have explained and illustrated my scheme in the fewest possible words. It is my sincere hope that other teachers, with better opportunities than mine, will be encouraged to criticise it, to emend it and to add the missing details. I have at best set forth a working hypothesis derived from such evidence as I have collected. It is for others to test this hypothesis by their own experience, and to deal with it as it deserves.

My belief in the value of a rigid application of scientific method to certain parts of all subjects has been steadily growing during the last six years. But the experience of one teacher is necessarily limited, and the time appears to have arrived when others should be asked to co-operate in drawing up a list of problems which lend themselves to inductive reasoning. My own impression is that the commonplace generalisations of the various subjects all afford excellent material, but experience, and experience only, can decide.

I do not, of course, hold that all teaching, or even the greater portion of it, ought to follow the lines I have laid down. It is only a part (to my mind a much neglected one) of education that I wish to emphasise. Periodically in the course of my school and university work a problem occurs which I do not like to dismiss summarily. To do so is the easier course, but I always feel that the opportunity should not be lost of practising my pupils in the fundamental principles of research. It is in such cases that the

plan which I advocate ought to be adopted, so that by the time he reaches the age of seventeen a boy may have some idea at any rate of the method in which a problem ought to be attacked, and can form a reasonable estimate of the accuracy or probability of his results. I cannot help thinking that such a power is an invaluable instrument for mastering, not only the difficulties of school work, but also those which will meet the pupil in the larger school of the world.

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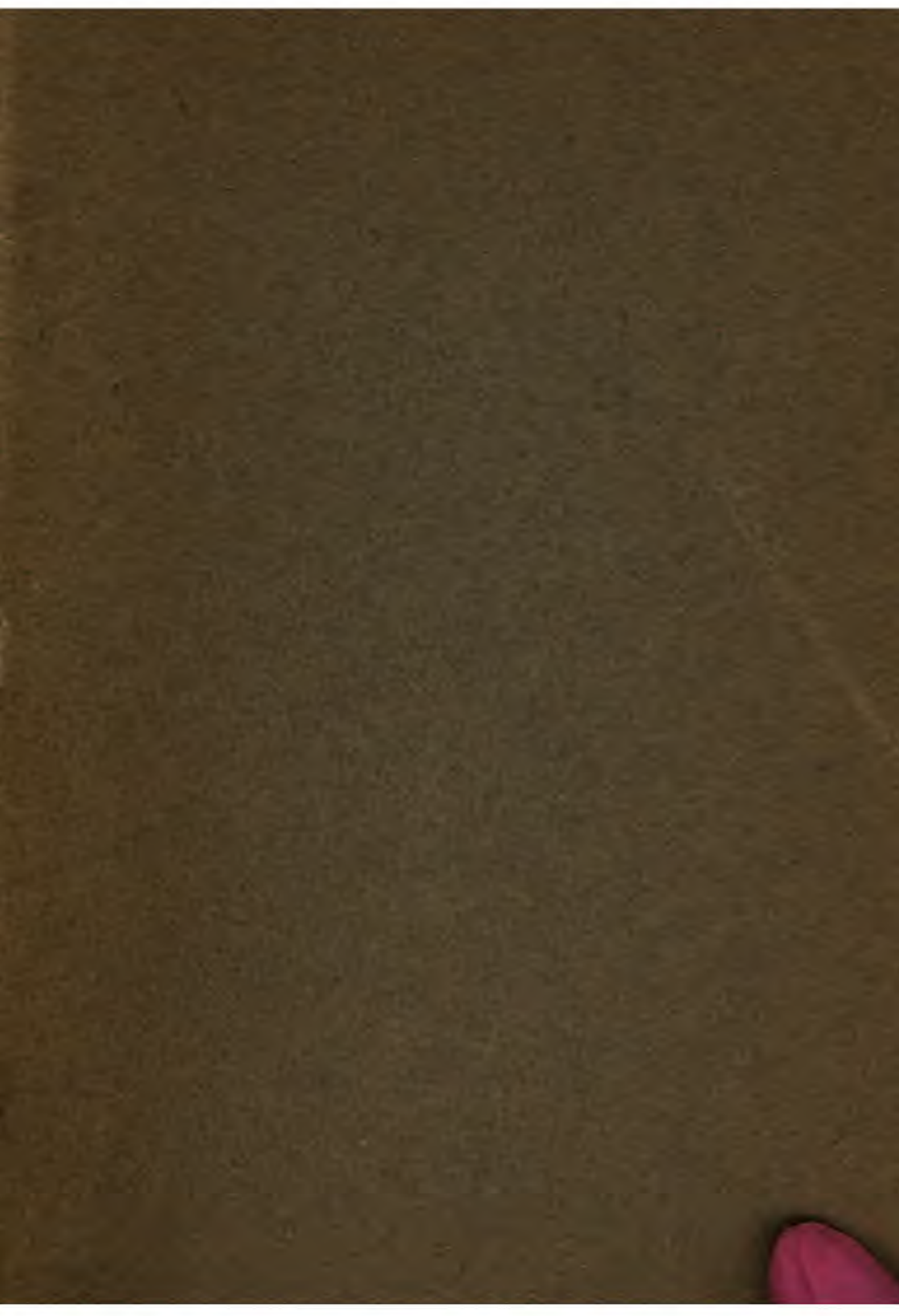
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